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COMMERCIAL CENTRAL TOWER POWER PLANTS: A BRIEF REVIEW

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Abstract. *The growing demand for energy and increasing environmental awareness have highlighted the renewable energies. Among these, the solar energy is gaining space and becoming popular, given its characteristics such as abundance of solar resource (irradiation) and ease of electric grid integration. To process solar energy, there are some options, of which Concentrating Solar Power (CSP) is recommended to generate large amounts of power. Thus, knowing the growth potential of CSP power plants for commercial applications, especially central tower plants, this study present an overview about the commercial central tower power plants with a minimal capacity of 5 MW and the Brazilian scenario concerning this technology. One can notice that despite the potential of the Central Tower (CT) plants and the evolution it has presented to date, it is necessary to mature the technology and, mainly, reduce costs for popularization in the market. In Brazil, there are two CT plants under development, however some studies concerning CSP technology in the county reflect the world scenario, in which CT plants are not economically competitive.*

Keywords: *Central Tower, Concentrating Solar Power, Solar Energy, Review*

1. INTRODUCTION

Today's society dependence on electricity is an unquestionable fact. According to data from the International Energy Agency (IEA), in 2014, 23.816 TWh of electricity were generated, amount which is almost four times the electricity generated in 1973 (IEA, 2016).

With the growth of world population, increase in consumption and technologies popularization, the trend is an always growing demand for energy. A major problem arises from this scenario: the need of an increasingly energy generation, but in a sustainable way.

Renewable energies are the option for the sustainable electricity generation, supplying, in 2014, 5,294 TWh (IRENA, 2016). In 2015, approximately one quarter (23.7%) of the electric energy was generated from renewable sources, with hydroelectric plants providing 16.6% of this total (REN21, 2016). Considering the reduced expansion capacity of hydroelectric plants, the alternative sources (solar, wind, geothermal and biofuels) will be responsible for increasing the renewables contribution in world's energy production.

Solar energy, particularly Concentrated Solar Power (CSP), stands out among the renewable sources because it can produce electricity in a stable and continuous way through the Thermal Energy Storage systems (TES), preventing discontinuities in the power generation, allowing the direct connection to the distribution grid.

The CSP technology consists in, basically, redirecting the incident solar rays at a point, using mirrors. This reflected irradiation is used to heat water, or other fluid, which will generate steam to power a turbine that, in turn, will produce electricity through a generator. The natural resource of interest in these systems is the Direct Normal Irradiance (DNI), that is the portion of Sun's irradiation that reaches Earth's surface without suffering any deviation or attenuation. The construction of a CSP plant is recommended at locations that receive at least 2,000 kWh/m²/year of DNI, although, in a near future, it is anticipated that locations with DNI values ranging 1600 to 1800 kWh/m²/year could also become economically feasible (Purohit and Purohit, 2017).

Today, four CSP plant configurations are available: Parabolic Through Collector (PTC), Linear Fresnel (LF), Parabolic Dish (PD) and Central Tower (CT or central receiver system, CRS). Each of these technologies has the same basic elements: mirrors, Heat Transfer Fluid (HTF), thermal engine and generator.

Despite having the same basic structure, each configuration differs in some aspect, for example: reflector shape, working temperature, efficiency, cost, thermal engine used, thermal storage system and hybridization possibility.

PTC technology is the most mature and commercially used. This system is relatively inexpensive and robust, allows the incorporation of TES and a hybrid system. PTC's limitation relies in its maximum working temperature. The system becomes inefficient when working at temperatures above 500 °C, preventing an effective use of the solar resource and energy storage.

The LF plants have low commercial representation, with only three plants in operation. One can say that LF plants aim the cost reduction, since its components are cheaper than the PTC. However, Fresnel systems are less efficient than PTC due to higher optical losses and lower working temperatures.

PD, today, is an experimental technology with only one commercial project in operation: Tooele Army Depot, with a production capacity of 1.5 MW (NREL, 2016a). These systems have high efficiency and high solar concentration factor, the highest among the four technologies. However, there is no possibility of TES incorporation and its installation is expensive.

The CT technology is the second most used in commercial applications. This configuration stands out because is competitive in the generation of large amounts of energy. CT plants consist of a central tower surrounded by a large number of mirrors, called heliostats. Each heliostat is programmed to track the sun and reflect the incoming irradiation into a receiver, located at the tower top. The receiver transfers the energy to the HTF, which may be water, for direct steam generation (DSG) or molten salts, which will pass through a heat exchanger to generate steam.

As all heliostats concentrate the energy in a small area, the temperatures obtained are higher than in the PTC and LF systems. This high temperature allows the use of gas turbines, which are more efficient than the steam turbines used in other systems. Thermal storage is also more efficient: due to the large amount of concentrated energy, which usually exceeds the generation demand, it is possible to store more energy, allowing the plant to operate up to 24 hours a day. The disadvantage of the central tower plants is the higher cost of installation when compared to PTC and LF plants.

To meet the increasing power demand with CSP technology, PTC or CT are usually chosen. The former for being less expensive and mature, and the latter for its large generating potential.

This way, knowing the potential of CT plants, the information about the commercial central tower power plants with more than 5MW was collected. Additionally, aiming to situate the reader on the current scenario and become a starting point for other works, the information about the studies and projects involving CT plants in Brazil was reviewed.

2. METHODS

The research was conducted in two stages. In the first stage, realized in January of 2017, *the Portal de Periódicos da CAPES* search tool was used to collect the basic information about the CT plants. The keywords employed were "Concentrated Solar Power" and "Review", with the following filters: peer revised journals and journal articles written in English from 2012 to 2017. Then, to update the data, the database from the United States National Renewable Energy Laboratory (NREL) and the plant's company websites were consulted.

The second stage, conducted in February and July of 2017, searched the keywords "Brazil", "Concentrated Solar Power" and "Potential" on *the Portal de Periódicos da CAPES* search tool, using the first step filters. In addition to this, the Brazilian government website about CSP (IBICT, 2017), was consulted.

3. RESULTS AND DISCUSSION

From the collected data, it was possible to create Fig. 1, which synthesizes the current scenario of commercial central tower plants in the world. It can be clearly seen that, CT is not widely used, with the operational plants concentrated in the United States and Spain. Also, is possible to see a small number of plants under construction, reflecting the market insecurity about this technology. However, the Fig. 1 shows that the future is promising, especially in China, which presents several projects under development.



Figure 1. Commercial central tower plants distribution in the world.

The details about the operational, under construction and under development plants, as well as the Brazilian scenario about CT plants are in following subsections.

3.1 Operational plants

The first steps in the development of CT plants occurred during the operation of EURELIOS, Solar One and Solar Two pilot plants, as described by Baharoon et al. (2015) in its review. These plants brought technologies such as molten salts and thermal storage, which made the central tower plants commercially viable.

Although technical knowledge was available, the construction and commercial operation of these plants was not attractive to the private sector. Hence, only with the fiscal incentive of the Spanish government, through Royal Decree 436/2004 (Spain, 2004), it was possible to implement the first CT plant of the world, Planta Solar 10.

PS10's construction, carried out by Abengoa Solar S.A., began in 2005 and ended in 2007, when it started delivering electricity to the grid. The project uses water steam as HTF and, given the difficulties of storing steam, has a small thermal storage, 30 minutes (Abengoa Solar S.A., 2014a), which keeps power generation at half the nominal capacity during the passage of clouds. In addition to the solar source, the PS10 relies on natural gas as a backup fuel, which gives the reliability necessary for the electricity production. Table 1 gives the other characteristics.

Table 1. Operational CT plants in the world.

Start year	Name	Location	Power (MW)	Area (km ²)	HTF	Number of heliostats	TES	Hybrid system	Source
2007	Planta Solar 10 (PS10)	Sevilha, Spain	11	0,6 ⁽²⁾	Water	624	30 min	Natural gas	(Abengoa Solar S.A., 2014a; NREL, 2015a)
2009	Planta Solar 20 (PS20)	Sevilha, Spain	20	0,85 ⁽²⁾	Water	1.255	1 h	Natural gas	(Abengoa Solar S.A., 2014a; NREL, 2015b)
2009	Sierra SunTower (Sierra)	Lancaster, USA	5	0,08 ⁽²⁾	Water	24.360	None	⁽¹⁾	(eSolar Inc, 2016; NREL, 2014a)
2011	Gemasolar Thermosolar Plant (Gemasolar)	Fuentes de Andalucía, Spain	19,9	1,95 ⁽³⁾	Molten salt	2.650	15 h. 2 tanks direct. Molten salt	None	(NREL, 2016b; Torresol Energy Investments S.A., 2010)
2014	Ivanpah Solar Electric Generating System (ISEGS)	Ivanpah Dry Lake, USA	377	14,2 ⁽²⁾	Water	173.500	None	None	(BrightSource Energy Inc, 2015a; NREL, 2014b)
2015	Crescent Dunes Solar Energy Project	Tonopah, USA	110	6,5 ⁽²⁾	Molten salt	10.347	10 h. 2 tanks direct. Molten salt	None	(NREL, 2016c; SolarReserve LLC, 2016a)
2016	Khi Solar One	Upington, South Africa	50	6 ⁽³⁾	Water/ Steam	4.120	2 h. Saturated steam.	⁽¹⁾	(Abengoa Solar S.A., 2014b; NREL, 2016d)
2016	SunCan Dunhuang 10 MW Phase I	Dunhuang, China	10	0,49 ⁽²⁾	Molten salt	1.525	15 h. 2 tanks direct Molten salt	⁽¹⁾	(NREL, 2017a)

⁽¹⁾Information not provided

⁽²⁾Plant total area

⁽³⁾Heliostat field area

Two years after the inauguration of PS10, Abengoa Solar S.A. began operating the PS20, the second commercial CT plant in the world. The design of the new plant, compared to PS10, pushed electricity production from 11 MW to 20 MW, and increased the number of heliostats and the area occupied as indicated in Tab.1. Using water as HTF, the PS20 amplified the thermal storage to 1 hour, improved control systems and the receiver, resulting in a 10% growth in power generation (NREL, 2015b). The environmental benefit was also enhanced, according to Abengoa Solar S.A. (Abengoa Solar S.A., 2014a), PS20 eliminates 12 thousand tons of CO₂ per year, twice more than PS10.

Also in 2009, the first commercial tower plant in the United States began operating. Located in Lancaster, Sierra SunTower consists of two 2.5 MW modules, uses water as HTF and has no thermal storage. Each of the modules has its own tower and heliostat field. The configuration of the field differs a lot from the Spanish plants because it uses 24,360 heliostats of reduced size: 1,136 m² of reflective area against 120 m² of reflective area of PS10 and PS20 heliostats. The explanation for this choice are the reduced heliostats production, maintenance and operational costs. Also, according to eSolar Inc (2016), the company which operates the plant, the project eliminates 7 thousand tons of CO₂ from the atmosphere per year.

In 2011, Gemasolar, the first plant to use molten salts as HTF and thermal storage fluid, began operation. The adoption of these salts allows the storage of sufficient energy to generate energy for 15 hours without solar light, thus, the plant operates 24 hours a day only with solar energy. From Tab. 1, it is possible to see that the number of heliostats used in Gemasolar is approximately twice the amount used at PS20, of similar capacity (20 MW). This is due to the large amount of stored energy at Gemasolar. To store energy, the field must collect more energy than demanded, needing a larger field to collect energy for the generation and storage systems. With this configuration, Gemasolar, according to Torresol Energy Investments S.A. (2010), avoids the emission of 27 thousand tons of CO₂ per year.

The largest central tower plant in operation began operations in 2013 (BrightSource Energy Inc, 2015a), in the United States. With a nominal power of 377 MW, the plant consists of 3 units: one of 126 MW and two of 133 MW (NREL, 2014b), each with its own tower. The working fluid is water, there is no TES system and natural gas is used as backup fuel. The energy production by the Ivanpah plant reduces carbon dioxide emissions by 400,000 tons per year (BrightSource Energy Inc, 2015a). It is important to highlight the initial difficulties of this plant, which could not reach the nominal power. This created a disbelief among investors and put into question the government funding until the problem was resolved. In addition, the issue of animal safety has arisen as the heliostats' concentrated rays killed birds in flight, promoting the development of animal protection techniques, as this is not a specific problem of the Ivanpah plant.

More recently, in 2015, the Crescent Dunes plant started operating in the United States. Generating 110 MW of electricity, it was the second in the world to use molten salts as HTF and incorporate a TES system with capacity for 10 hours of operation without sunlight, which eliminates the need for a hybrid system. With Crescent Dunes, it was possible to show the potential of central tower CSP plants because, according to SolarReserve LLC (2016), this plant produces twice as much electrical energy as a photovoltaic plant of the same size.

The newest commercial projects were inaugurated last year, 2016, in Upington in South Africa (NREL, 2016d) and in Dunhuang, China (NREL, 2017a). With a generation of 50 MW, Khi Solar One uses water as HTF and, therefore, its thermal storage uses saturated steam. For a reduction of two-thirds in water consumption during the plant operation, dry cooling is used. The electricity generated by Khi Solar One will avoid the emission of 183 thousand tons of CO₂ per year. The SunCan plant is the first CT plant in China and follows the trend of central tower projects: molten salts as HTF and large thermal storage systems.

3.2 Under construction plants

Currently, there are 5 plants under construction, two with inauguration scheduled for 2017, two for 2018 and another with no forecast, as shown in Tab. 2. One can see that the molten salts are preferred in these plants and that these projects have thermal reservoirs of great capacities: Supcon Solar, SunCan Dunhuang, NOORo III, Atacama I and Golmud will have, respectively 6, 11, 8, 17, 5 and 15 hours of thermal storage.

The exception to the molten salts trend is the Ashalim Plot B plant, in Israel, which will use water as HTF and will not have TES or backup fuel. This plant is part of the Israeli government's plan to have ten percent of its electricity production from renewable sources by 2020. When in operation, it will avoid the emission of 110,000 tons of CO₂ per year (BrightSource Energy Inc, 2015b).

Among the under construction plants, Atacama I, located in the region with the highest incidence of solar irradiation in the world (Abengoa, 2015), is the only that include a photovoltaic field, which will produce an additional 100 MW, resulting in 210 MW generated by hole plant. This project is part of the Chilean government initiative to have 20 percent of its energy production from clean sources by 2025, thereby developing the region's economy and reducing its dependence on coal and natural gas (Abengoa, 2015). The energy generated at the Atacama I plant will prevent the emission of approximately 643,000 tons of CO₂ per year.

Located in Morocco, the NOORo III plant will have Gemasolar's configuration, but will generate more electricity, 150 MW, will use 7,400 redesigned heliostats and will have a smaller storage (SENER group, 2016). According to SENER, responsible for the project, it will be possible to avoid the emission of 130 thousand tons of CO₂ per year.

Table 2. Plants under construction in the world.

Start year	Name	Location	Power (MW)	Area (km ²)	HTF	Number of heliostats	TES	Hybrid system	Source
2017	Ashalim Plot B	Ashalim, Israel	121	⁽¹⁾	Water/Steam	50.600	None	None	(BrightSource Energy Inc, 2015b; NREL, 2016e)
2017	NOORo III	Ouarzazate, Morocco	150	5,5 ⁽²⁾	Molten salt	7.400	8 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2015c; SENER group, 2016)
2018	Atacama I	Calama, Chile	110	10 ⁽²⁾	Molten salt	10.600	17,5 h. 2 tanks direct. Molten salt	PV plant with 100 MW of additional power generation	(Abengoa, 2015; Abengoa Solar S.A., 2014c; NREL, 2015d)
2018	Golmud	Golmud, China	200	25 ⁽²⁾	Molten salt	⁽¹⁾	15 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016f)
⁽¹⁾	SunCan Dunhuang 100 MW Phase II	Dunhuang, China	⁽¹⁾	⁽¹⁾	Molten salt	⁽¹⁾	11 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2017b)
⁽¹⁾	Supcon Solar Project	Delingha, China	50	3,3 ⁽²⁾	Molten salt	217.440	6 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016g)

⁽¹⁾Information not provided

⁽²⁾Plant total area

⁽³⁾Heliostat field area

The other plants under construction are located in China and are part of the Chinese government's project to create a large solar park. The Golmud plant will be the second largest central tower plant in the world, with 200 MW, generated by two 100 MW turbines. The Construction of SunCan Dunhuang 100 MW Phase II plant, which has no inauguration date scheduled, complements the already built SunCan Dunhuang 10 MW Phase I project. Together, these plants will deliver 110 MW. The Supcon Solar plant draws attention to the large number of heliostats, since, from Tab. 2, it is possible to observe projects that produce more power with fewer heliostats. This large figure is explained by the use of smaller heliostats than commonly used heliostats: they will have 2 m² of surface area in contrast to the 20.8 m² and 140 m² that will be used in the Ashalim Plot B and Atacama I plants, respectively.

3.3 Under development plants

The increasing development and government subsidies drive the emergence of new plans for construction of CT plants, as presented in Tab. 3. A growth can be observed by comparing Tab. 3 of this work with Tab. 9 and 5 of Baharoon et al. (2015) and Behar, Khellaf and Mohammedi (2013), respectively. It is important to note that some projects, such as Rio Mesa, Coyote Springs 1 and 2 and BrightSource 5, 6 and 7, announced in these works were canceled by the request of the responsible companies (State Of California Energy Commission, 2017a, 2017b). Part of these cancellations was stimulated by the difficulties and doubts created during the first years of the pioneer plants, such as Ivanpah.

Despite this, it is possible to notice that there is no distribution homogeneity of projects around the world: there are two concentration areas, one with 8 projects in China and another with 3 projects in Chile.

In China, only two projects, Delingha Qinghai 135 MW DSG and Shangyi 50 MW DSG, will use water as HTF, contrasting with the great trend of molten salts utilization. The innovation of these two developments is the indirect thermal storage system, that will use molten salts and not saturated steam, as in previous plants.

Table 3. Plants under development in the world.

Start year	Name	Location	Power (MW)	Area (km ²)	HTF	Number of heliostats	TES	Hybrid system	Source
2017	Delingha Qinghai 135 MW DSG Tower CSP Project	Delingha, China	135	13 ⁽²⁾	Water/steam	⁽¹⁾	3,7 h. 2 tanks direct. Molten salt	⁽¹⁾	(BrightSource Energy Inc, 2015c; NREL, 2016h)
2018	Redstone Solar Thermal Power Plant	Postmasburg, South Africa	100	⁽¹⁾	Molten salt	⁽¹⁾	12 h. 2 tanks direct. Molten salt	None	(NREL, 2016i; SolarReserve LLC, 2016b)
2019	Copiapó	Copiapó, Chile	260	⁽¹⁾	⁽¹⁾	⁽¹⁾	13 h. 2 tanks direct. Molten salt	PV plant with 150 MW of additional power generation	(NREL, 2015e; SolarReserve LLC, 2016c)
2019	Jemalong 30 MW	New South Wales, Australia	30	⁽¹⁾	⁽¹⁾	65.000	4 h minimum	⁽¹⁾	(Vast Solar Pty Ltd, 2016)
⁽¹⁾	Atacama II	Sierra Gorda, Chile	110	⁽¹⁾	Molten salt	⁽¹⁾	15 h. 2 tanks direct. Molten salt	PV plant with 100 MW of additional power generation	(Abengoa, 2015)
⁽¹⁾	Crete	Creta, Greece	50	1,6 ⁽²⁾	Steam	⁽¹⁾	⁽¹⁾	⁽¹⁾	(Nur Energie Ltd, 2016a)
⁽¹⁾	Dunhuang 100 MW Molten Salt CSP Project	Dunhuang, China	100	⁽¹⁾	Molten salt	⁽¹⁾	11 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016j)
⁽¹⁾	Golden Tower 100 MW Molten Salt Project	Jinta, China	100	⁽¹⁾	Molten salt	⁽¹⁾	8 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016k)
⁽¹⁾	Hami 50 MW CSP Project	Hami, China	50	⁽¹⁾	Molten salt	⁽¹⁾	8 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016l)
⁽¹⁾	María Elena thermosolar plant	María Elena, Chile	400	28,97 ⁽²⁾	Molten salt	35.200	(1)	⁽¹⁾	(Grupo Ibereólica, 2011)
⁽¹⁾	Qinghai Gonghe 50 MW CSP Plant	Gonghe, China	50	⁽¹⁾	Molten salt	⁽¹⁾	6 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016m)
⁽¹⁾	Shangyi 50 MW DSG Tower CSP Project	Shangyi, China	50	⁽¹⁾	Water/steam	⁽¹⁾	4 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016n)
⁽¹⁾	TuNur	Rjim Maatoug, Tunisia	2.500	100 ⁽²⁾	Molten salt	⁽¹⁾	Molten salt	⁽¹⁾	(Nur Energie Ltd, 2016b)
⁽¹⁾	Yumen 100 MW Molten Salt Tower CSP Project	Yumen, China	100	⁽¹⁾	Molten salt	⁽¹⁾	10 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016o)
⁽¹⁾	Yumen 50 MW Molten Salt Tower CSP Project	Yumen, China	50	⁽¹⁾	Molten salt	⁽¹⁾	6 h. 2 tanks direct. Molten salt	⁽¹⁾	(NREL, 2016p)

⁽¹⁾Information not provided

⁽²⁾Plant total area

⁽³⁾Heliostat field area

In Chile, despite presenting only three projects, there will be a larger total generation than in China, with 8 projects: 770 MW generated in Chile against 665 MW produced in China. This generated power figure can be higher, because two of the Chilean projects, Copiapó and Atacama II will have photovoltaic fields for extra electricity production. The use of molten salts is unanimous in Chile, because all the projects will have large TES systems, as shown in Tab. 3, and Chile has great reserves of the salts used as HTF. It is important to highlight that, when completed, the Maria Elena plant will be the largest in the Americas, with a production of 400 MW.

However, the country that will have the largest power generation through CT plants will be Tunisia, which will produce 2,500 MW of clean energy with this technology. Tunur is the name of the project, which will be built in two stages (one of 250 MW and another of 2,250 MW) and will bring electricity generated in Africa to Europe, helping the latter to decarbonize its grid (Nur Energie Ltd, 2016b).

Also on the African continent, in South Africa, the Redstone plant is under development. This plant will work in conjunction with two photovoltaic parks, Lesendi and Jasper, totaling a production of 271 MW (NREL, 2016i).

In Australia, the Jemalong project comes up with a configuration that sets it apart from the others: there will be 90 power generation modules, each containing 700 heliostats and a 27 m high tower. A thermal reservoir with a storage time of at least 4 hours will also be present (Vast Solar Pty Ltd, 2016).

Europe has only one project to be built in Greece. The plant, still unnamed, will generate 50 MW of electricity and will use steam as HTF.

3.4 CT plants in Brazil

In Brazil, there is no operational or under construction CT plant. However, three CT projects were announced in the country: one of them, a project under the responsibility of Petrobrás and partners, which intended to build a 3 MW plant in Vale do Açu – RN, has been canceled. The SMILE project, coordinated by GREEN/USP research group, aims the construction of two plants with a capacity of 100 kW each for to generate electricity and heat (IBICT, 2017), has no status information, which may indicate that the construction start has been postponed. The third project, Planta Tecnológica, part of the Solar Energy Reference Center (Cresp) structure, will include the installation of a pilot CT plant for research in Petrolina - PE until the end of 2018.

Among the search results, only the works of Fonseca, Poganietz and Gehrmann (2014) and Malagueta et al. (2014) address CT plants in Brazil. Both analyze, with different objectives, the plant operation with a hybrid system. The conclusion is, respectively: the proposed system is economically less interesting than hydroelectric plants, being necessary, however, a more refined analysis is necessary. The hybridization of sugarcane bagasse cogeneration power plants equipped with BPST and CEST with CSP, mainly in the central tower format, turns possible to improve the annual electricity output of these plants by maximizing their capacity factor while providing additional off-season operation.

4. CONCLUSIONS

Renewable energies emerge as an alternative to the use of fossil fuels, reducing the environmental impact and supplying the growing world energy demand. Among the available options, solar energy, especially the CSP, stands out for its power generation, robustness and versatility.

The central tower plants, among the possible configurations of CSP plants, demonstrate great application potential to generate large amounts of power due to the ease of hybridization, TES systems and higher working temperatures.

However, the global cost of CT plants is a barrier to its popularization on the market, so that, in order to gain relevance, cost reduction is fundamental. Thus, it is necessary to invest in researches that aim the technology improvement, like the ones cited here: an efficient heliostat distribution by Collado and Guallar (2016) and Atif and Al-Sulaiman (2015), the proposal of a new tracking system by Ashith Shyam and Ghosal (2015), the comparison between power cycles configurations in Al-Sulaiman's and Atif's (2015) work, receivers and HTF, as exemplified by the studies of Kim, Kim and Stein (2015) and Boerema et al. (2012) respectively.

Local governments also play a key role in this reduction, because by introducing new projects, attracted with tax incentives, the technology learning curve will be accelerated, which will cheapen the plant components.

In Brazil, the same economic barriers are faced for CT plants implementation. One can see that the CSP future in the country will probably use PTC plants, as simulated by Fichter et al. (2017), Malagueta et al. (2014), and Soria et al. (2016), since PTC presents lower costs and greater technological maturity, factors that favor the CSP plants implantation. It is expected that, with the construction of the announced projects, SMILE and Planta Tecnológica, the real costs and challenges of building CT plants in Brazil will be better known, allowing a more precise analysis of these plants potential in the country.

For future works, the mapping of the country's real CSP potential, as done for India by Purohit and Purohit (2017) is needed. This survey will allow easy identification the potential areas, excluding the unsuitable sites and showing the particularities of each area (i.e. distance to transmission lines, water availability and access roads), thus allowing the planning and adequacy to receive future investments.

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